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Sealed-Off CO_2 Laser Discharge Parameter Study

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ABSTRACT

This report presents experimental data on the output power and efficiency of the sealed-off CO_2 laser as a function of discharge current, the initial fill pressures of CO_2 and He, and the tube diameter. The optimum fill pressure of pure CO_2 for maximum power output and efficiency was found to be approximately 5/d Torr, where d is the tube diameter expressed in cm. At this pressure the optimum current for maximum power output was about 7d mA. The output power can be increased by a factor of five with the addition of about 10 Torr of He. With He, the optimum current for maximum power output was approximately 18d mA.

PROBLEM STATUS

An interim report on one phase of a continuing problem.

AUTHORIZATION

NRL Problem R08-45
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SEALED-OFF CO_2 LASER DISCHARGE PARAMETER STUDY

INTRODUCTION

The carbon dioxide laser can operate sealed off for long periods (1-4) with only a small sacrifice in output power as compared with conventional flowing gas systems. The convenience of not having to provide a gas supply and pump, plus the saving of pump power, make the sealed-off system attractive for many applications. A sealed tube is an economic necessity when expensive isotopic species of CO_2 are used (5,6), or in countries where helium is very scarce.

The purpose of this report is to present experimental data on the output power and efficiency of the sealed-off CO_2 laser as a function of the discharge current, the initial fill pressures of CO_2 and helium, and the tube diameter. These data can be used to determine optimum fill pressures and operating currents for various qualities desired in the laser, such as maximum power output or efficiency. Similarity laws can be proposed for other tube diameters.

Carbon monoxide can be nearly as effective as nitrogen in pumping the upper laser level (7). The energy resonance between the v = 1 level of CO and the (00°1) level of CO_2 is well within kT. The use of N_2 is unnecessary in a sealed-off system because CO is present due to dissociation unless a special catalyst is used.

Since a sealed CO_2 laser would be used more often as an oscillator rather than as an amplifier, and since gain data neglect saturation effects due to the lower laser level, only output power data were taken.

DESCRIPTION OF EXPERIMENT

Apparatus

All of the laser tubes were of Pyrex construction, with water-jacketed discharge sections cooled with flowing tap water. The molybdenum electrodes, mounted in side-arm bulbs, are hollow-cylinder anodes taken from 5D22 transmitting tubes. A ceramic collar was added to the electrode to prevent sputtering by the discharge from the sharp edge. Sodium chloride windows were epoxied (8) on at the Brewster angle and protected from moisture by polyethylene enclosures containing a desiccant.

The tubes were processed on systems capable of ultrahigh vacuum and were extensively degassed with electric discharges and heat so that the background contamination was reduced to a minimum. Research-grade gases were used in all tests. The major impurities in the CO_2 were O_2 and N_2 at 8 ppm each. The gas pressures were measured to 0.02 Torr, independent of gas composition, by an oil manometer read with the aid of a cathetometer. The laser output power was measured with a Coherent Radiation Laboratories Model 201 power meter, accurate to ±5 percent of full scale (according to the manufacturer) and repeatable to about 1 percent. The discharge current was measured by the voltage drop across a 50-Ω resistor. Tube voltage was measured with an electrostatic voltmeter.

Three different tube geometries were used: 10 mm in diameter by 86 cm long, 19 mm in diameter by 150 cm long, and 38 mm in diameter by 180 cm long. The 10-mm-bore tube had two NaCl Brewster-angle windows and external gold-coated quartz mirrors with 3-m radii of curvature. The output coupling was provided by a 3-mm-diameter hole in one mirror. This was not the optimum coupling for maximum power output, but was the best of the limited number of mirrors we had available.

The 19-mm-bore tube had two internal mirrors. The output mirror was an uncoated germanium etalon which was edge mounted on a copper ring for conduction cooling. The faces of the 3-mm-thick etalon were flat and parallel to within 15 sec of arc. The opposite mirror was gold-coated quartz with a 4.9-m radius of curvature. Both mirrors were attached to the tube by means of flexible metal bellows, such that independent orthogonal adjustments were provided for both mirrors. Again, this mirror configuration was probably not optimum for maximum power output.

The 38-mm-bore tube had on one end a gold-coated quartz mirror with a radius of curvature of 9.8 m, which was mounted internally in the manner described above. The output end was terminated with a NaCl Brewster-angle window and a gold-coated, stainless steel, flat mirror with a 5-mm coupling hole. The negative electrode was the same as the electrodes in the other tubes, but the positive electrode was a Kovar cylinder sealed directly into the active discharge section of the tube. Again the mirror configuration was probably not optimum for maximum power output.

Procedure

The tube under test was evacuated to about 10^{-6} Torr. Carbon dioxide was admitted to approximately the pressure desired, and the pressure accurately measured. Then helium was added in the same manner. The discharge was turned on, and the current adjusted to yield maximum output power. The tube was allowed to operate at this current for about 3 hours, after which time the pressure was again measured. The reasons for this time interval were, first, to allow the dissociation of CO_2 into CO and O_2 and this recombination to approach an equilibrium condition and, second, to allow sufficient time for the gases to mix.

The cavity mirrors were carefully aligned by the walking technique (9), which ascertained that the mode volume of the radiation field occupied the maximum volume of the discharge tube so that maximum laser power was extracted from the discharge. Then the output power and the tube voltage were measured at selected current values, ranging from the lowest current at which a discharge could be maintained to the highest current at which laser output could be detected (or to the limit of the power supply). The measurements were completed about 3-1/2 hours after the discharge had been turned on.

RESULTS AND DISCUSSION

The results are presented in computer-drawn graphs using a least-squares polynomial program. A polynomial was not always the best curve to use for fitting the data points, but it did work well for most of the graphs. The data are presented first for pure CO_2, then for CO_2 plus helium, and finally for helium plus CO_2.

Pure CO_2

Figure 1 shows output power as a function of discharge current for various CO_2 pressures for each of the three tube diameters. From the graphs, the optimum fill pressure of CO_2 for maximum power output is approximately 5/d Torr, where d is the tube diameter in cm. At this pressure the optimum current for maximum power output is about 7d mA. For each tube diameter, the decrease in laser power with increasing pressure is probably due to the decrease of the average electron energy from the optimum values for exciting the asymmetrical stretch vibrational state of CO_2, either directly or via collisions with CO. The lower laser level is preferentially populated by higher gas temperatures due to higher discharge currents. Hence, the falloff of laser power at higher currents is due to a thermal bottleneck at the lower laser level. The optimum current would be higher and the output greater if the gas were more efficiently cooled.

Figure 2 shows the potentials across the tube as functions of current for each CO_2 pressure. At the optimum pressure and current for maximum power output, the ratio of the axial electric field strength divided by the pressure E/p is approximately 25 V/(cm Torr) for all three tube diameters. The constancy of this ratio implies (10) that the average electron energy is the same in all three tubes under maximum output power conditions, as might be expected.

From the data of Figs. 1 and 2, Fig. 3 was derived, which shows the power efficiency as a function of current for each tube diameter and CO_2 pressure. The optimum pressures are the same for both maximum efficiency and output power. However, the efficiency curves peak at significantly lower current values than do the output power curves.

Again from the data of Figs. 1 and 2, Figs. 4, 5, and 6 show maximum efficiency, output power, and optimum current, respectively, as functions of the CO_2 fill pressure.

Figure 7 shows the total pressure after 3 hours of operation as a function of the initial fill pressure of CO_2. The pressure increase is due to the dissociation of CO_2 into CO and O_2. These were the only molecules found in a spot check mass spectrometric analysis. From Fig. 7a, it is calculated that the percent dissociation after 3 hours of operation ranges from about 75 percent at 1.71 Torr to approximately 40 percent at 8.95 Torr. The decrease in percent dissociation with increasing pressure is partly due to the lower operating currents at the higher pressures (3 mA at 8.95 Torr vs 12 mA at 1.71 Torr).

Carbon Dioxide Plus Helium

The role of helium in the CO_2 laser discharge is twofold. First, helium collisionally deexcites the CO_2 lower laser level through intramolecular vibrational energy transfer (11, 12). Second, helium increases the thermal conductivity (13) of the laser gas so that the gas remains cooler and the Boltzmann population of the lower laser level is reduced.

The CO_2 pressure was set at the value found optimum in the previous section, and the helium partial pressure was varied as a parameter. From Fig. 8, it can be seen that the output power can be increased by a factor of five with the addition of helium. The optimum current for maximum power output is then approximately 18d mA, which is a factor of about 2.6 higher than without helium. These increases in output power and optimum current result from the collisional deexcitation and cooling effects of helium.

Figure 9 shows tube voltage vs current for various helium pressures. For optimum pressures of helium and optimum currents for maximum power, the E/p ratio* is about 35 V/(cm Torr) for all three tube diameters.

*Here, p is the partial pressure of CO_2, since the dominant excitation loss is due to inelastic collisions with CO_2.

The power efficiency as a function of discharge current with the helium partial pressure as parameter is shown in Fig. 10. With helium present the optimum current for maximum efficiency is about a factor of two higher than the optimum current without helium. The maximum efficiency with helium is about 50 percent greater than without helium.

Figures 11 and 12 show maximum efficiency and maximum output power, respectively, as functions of the partial pressures of helium. The optimum currents for maximum efficiency and output power are plotted in Fig. 13 as functions of the helium partial pressure. Again the optimum current for maximum efficiency is significantly lower than the optimum current for maximum power output.

Figure 14 shows the total pressure after 3 hours of operation vs the partial pressure of helium. The fact that the curves are straight lines with slopes of about one indicates that helium has little effect on the dissociation of CO_2 in the first 3 hours of operation.

Helium Plus Carbon Dioxide

In the series of measurements in which CO_2 was added to helium, the partial pressures of helium were fixed near the optima found in the previous section, while the partial pressures of CO_2 were again varied. This type of data was taken for the 10- and 19-mm-bore tubes only. The output power vs discharge current for various CO_2 partial pressures is shown in Fig. 15. The tube voltage as a function of discharge current is shown in Fig. 16 for these CO_2 partial pressures. On comparison with Fig. 9, it can be seen that the tube voltage drop is about three times more sensitive to changes in the CO_2 fill pressure than it is to changes in the partial pressure of helium.

Figure 17 shows power efficiency as a function of discharge current, with the CO_2 partial pressure as a parameter. Figures 18 and 19 show maximum efficiency and maximum power, respectively, as functions of the CO_2 partial pressure. A comparison with Figs. 4 and 5 shows that the optimum CO_2 fill pressure is slightly higher when helium is present. The optimum fill pressure of CO_2 for maximum power output is approximately 5.7/d Torr, with 12 to 15 Torr of helium in the tube.

Finally, Fig. 20 shows the optimum currents for maximum output and efficiency as functions of the CO_2 partial pressure. As before, the optimum current for maximum efficiency is significantly less than the optimum current for maximum output.

SUMMARY

The optimum fill pressure of pure CO_2 for maximum power output and efficiency was found to be approximately 5/d Torr, where d is the tube diameter expressed in centimeters. At this fill pressure the optimum current for maximum power output was about 7d mA. The output power can be increased by a factor of five with the addition of about 10 Torr of helium. With helium, the optimum fill pressure of CO_2 was about 5.7/d Torr, and the optimum current for maximum power output was about 18d mA.

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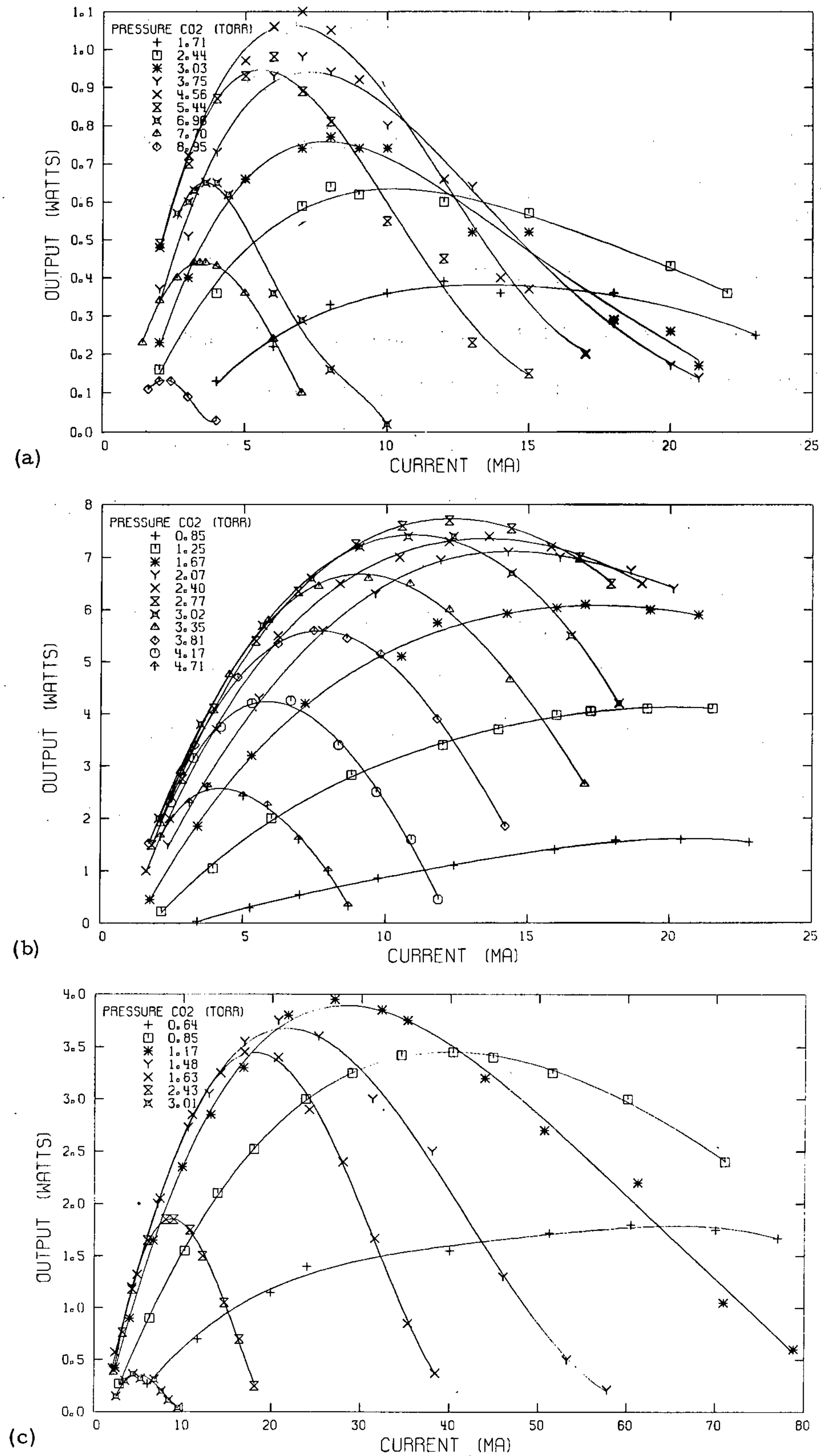

Fig. 1 - Laser output power as a function of discharge current for various CO_2 fill pressures (a) 10-mm bore, (b) 19-mm bore, (c) 38-mm bore

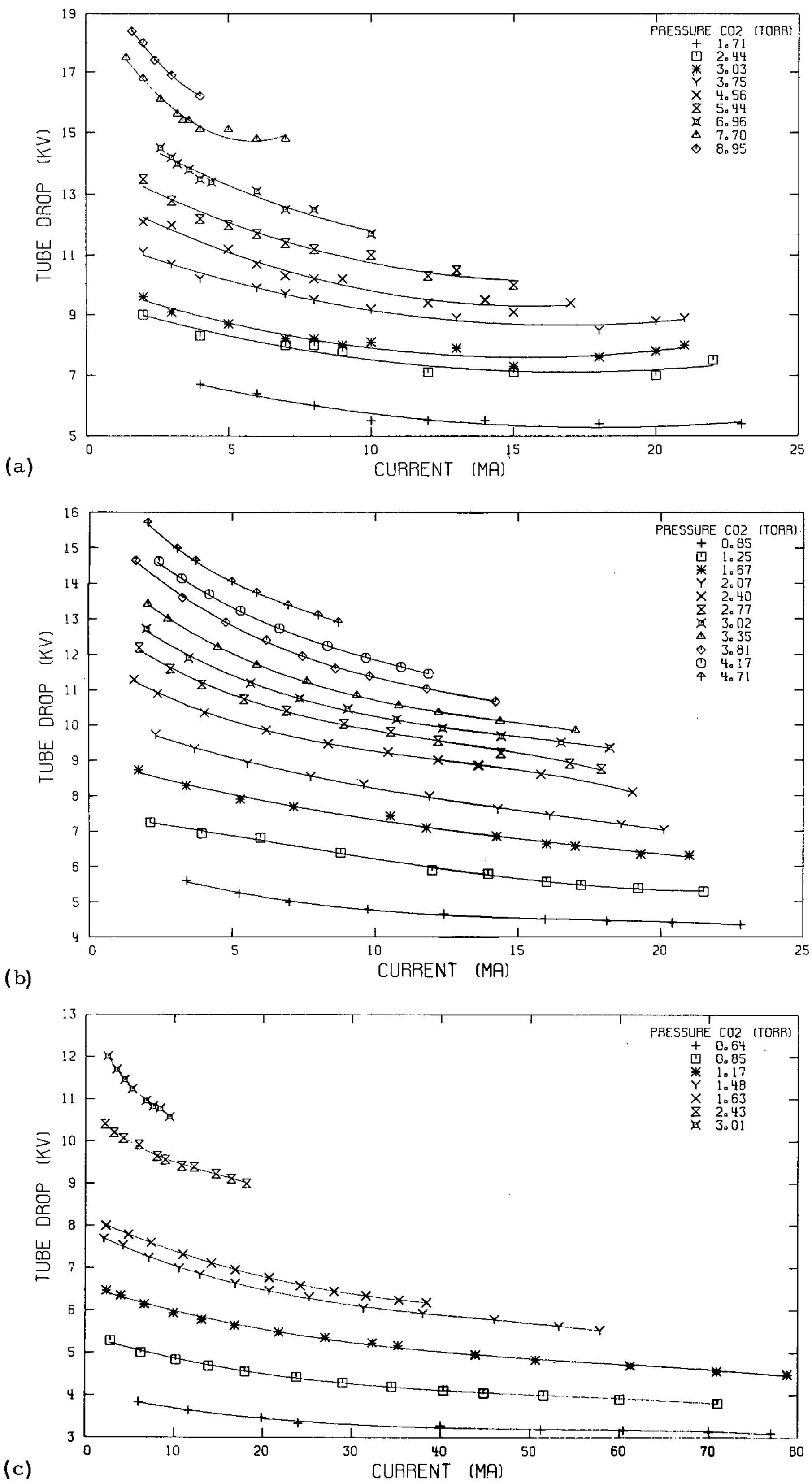

Fig. 2 - Potential drop across the discharge tube as a function of current for each CO_2 fill pressure (a) 10-mm bore, (b) 19-mm bore, (c) 38-mm bore

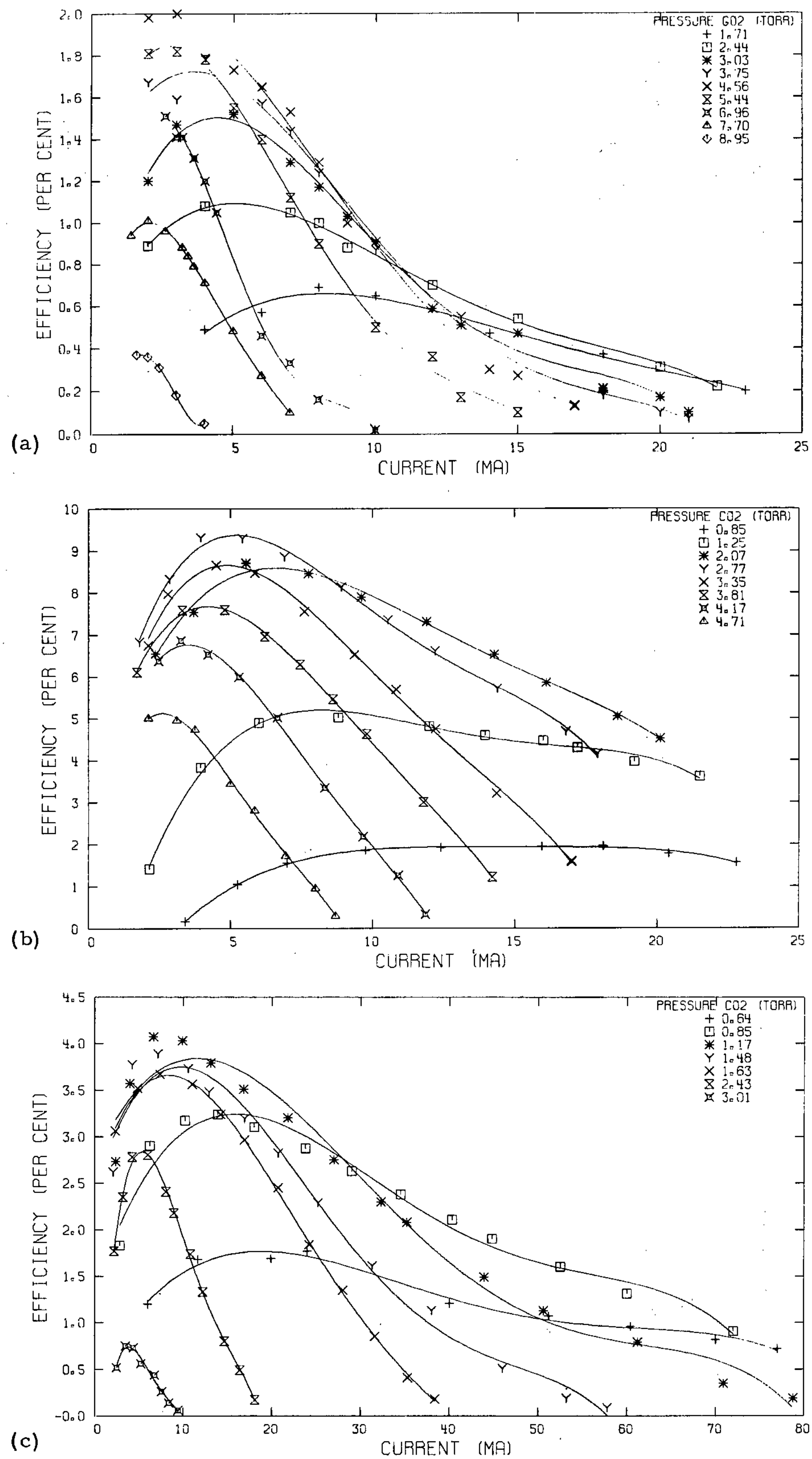

Fig. 3 - Power efficiency as a function of current for each CO_2 fill pressure (a) 10-mm bore, (b) 19-mm bore, (c) 38-mm bore

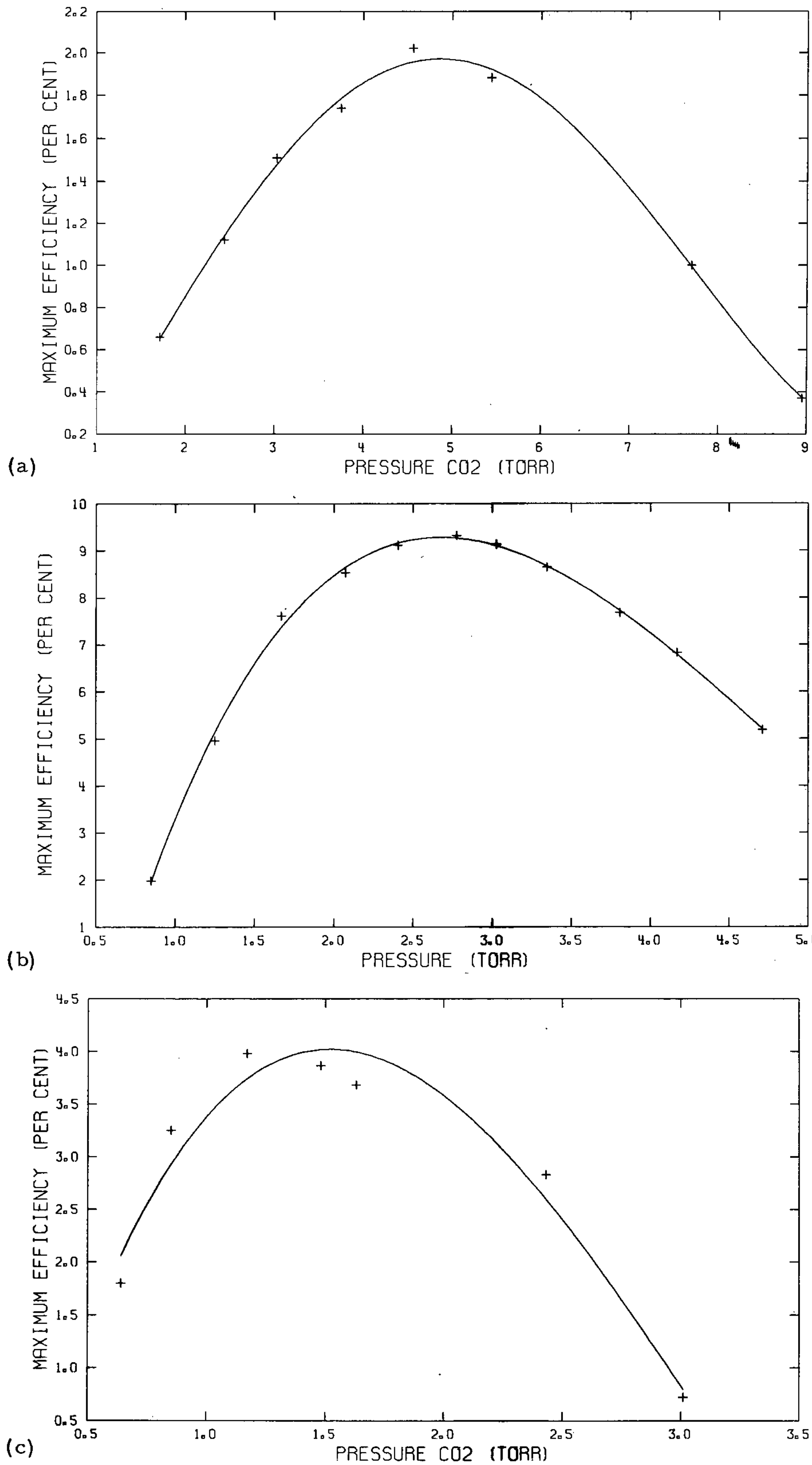

Fig. 4 - Maximum efficiency as a function of the CO_2 fill pressure (a) 10-mm bore, (b) 19-mm bore, (c) 38-mm bore

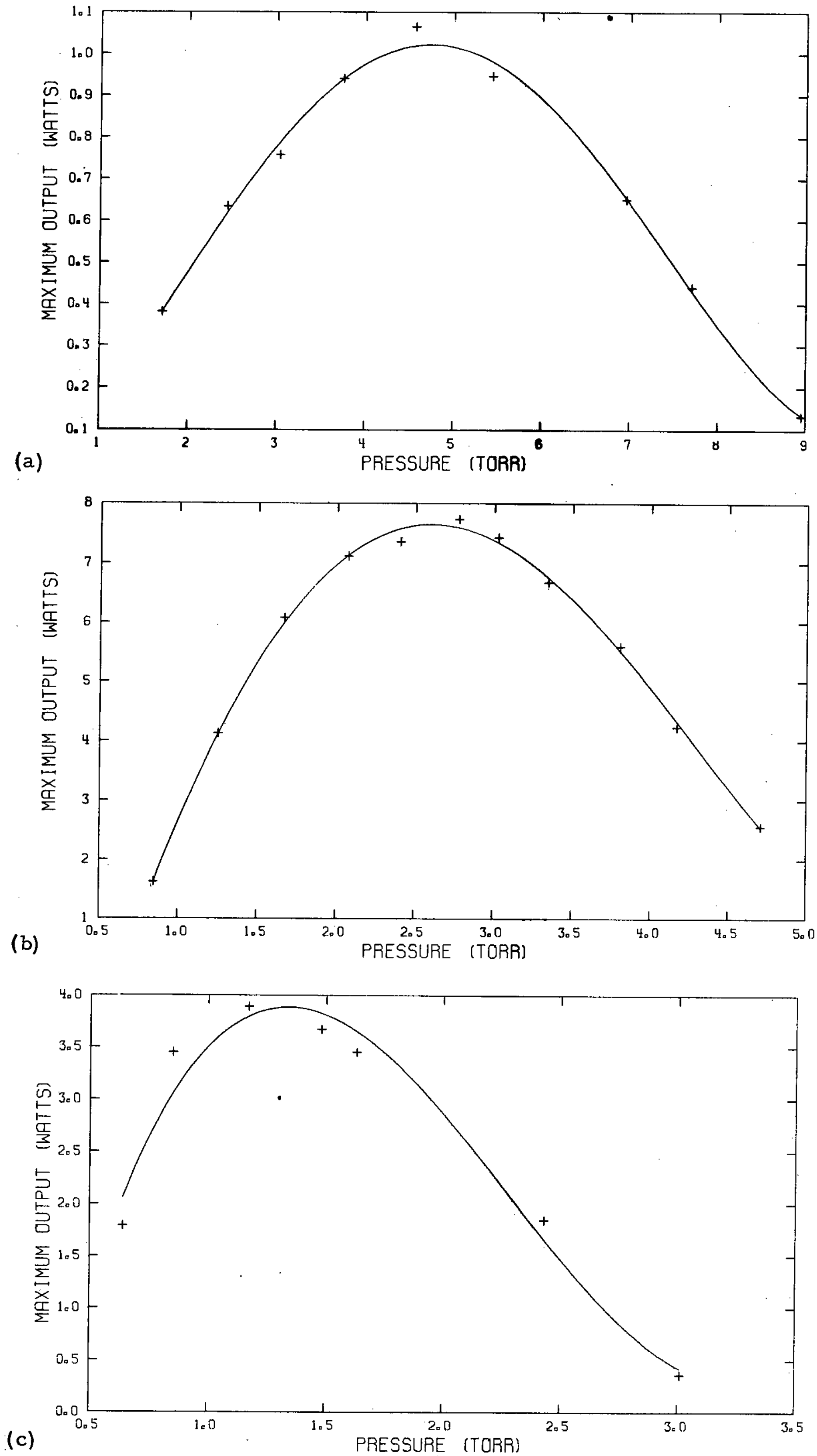

Fig. 5 - Maximum output power as a function of the CO_2 fill pressure (a) 10-mm bore, (b) 19-mm bore, (c) 38-mm bore

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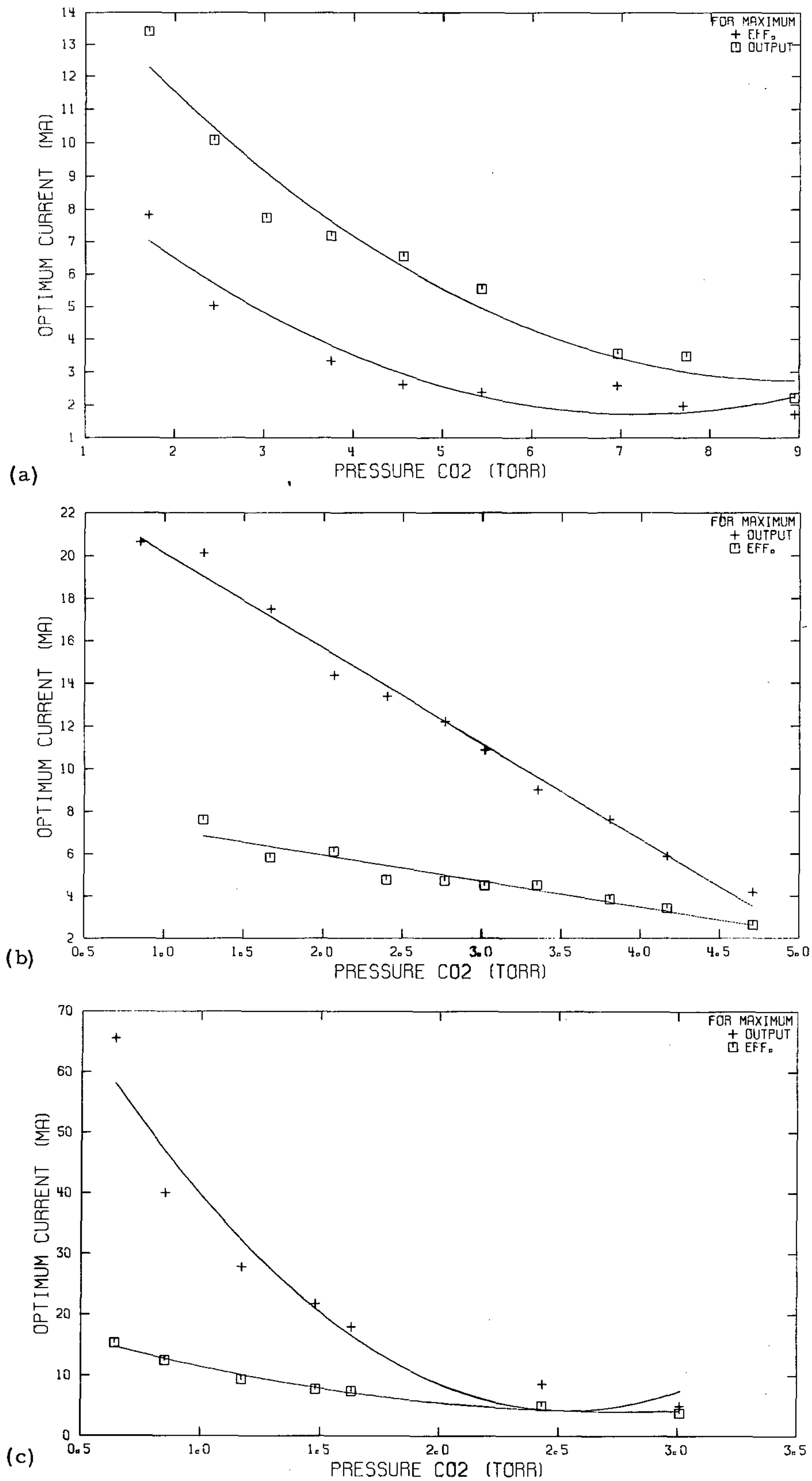


Fig. 6 - Optimum currents for maximum output power (upper curve) and for maximum efficiency (lower curve) as functions of the CO_2 fill pressure (a) 10-mm bore, (b) 19-mm bore, (c) 38-mm bore

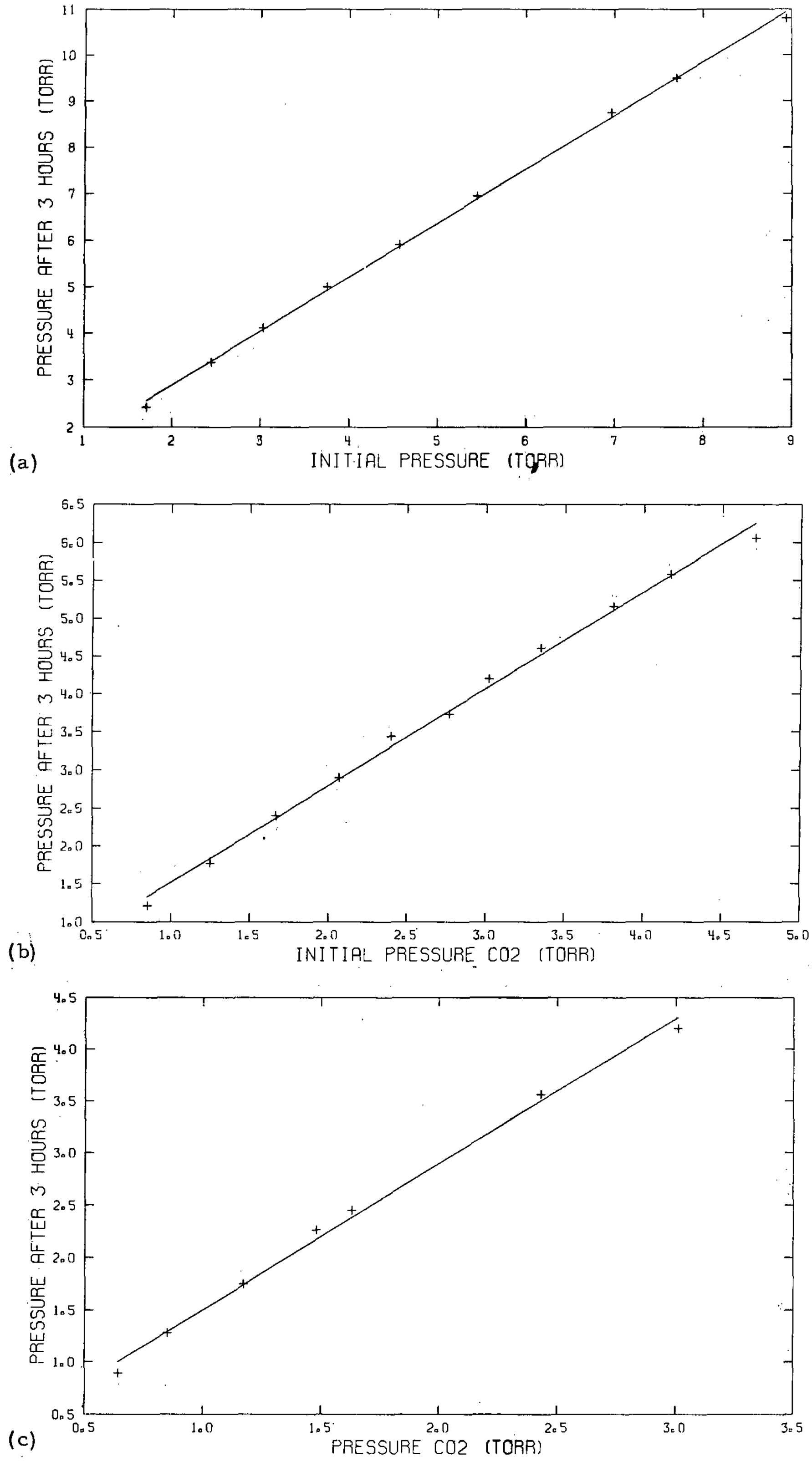


Fig. 7 - Total pressure after 3 hours of operation as a function of the initial fill pressure of CO_2 (a) 10-mm bore, (b) 19-mm bore, (c) 38-mm bore

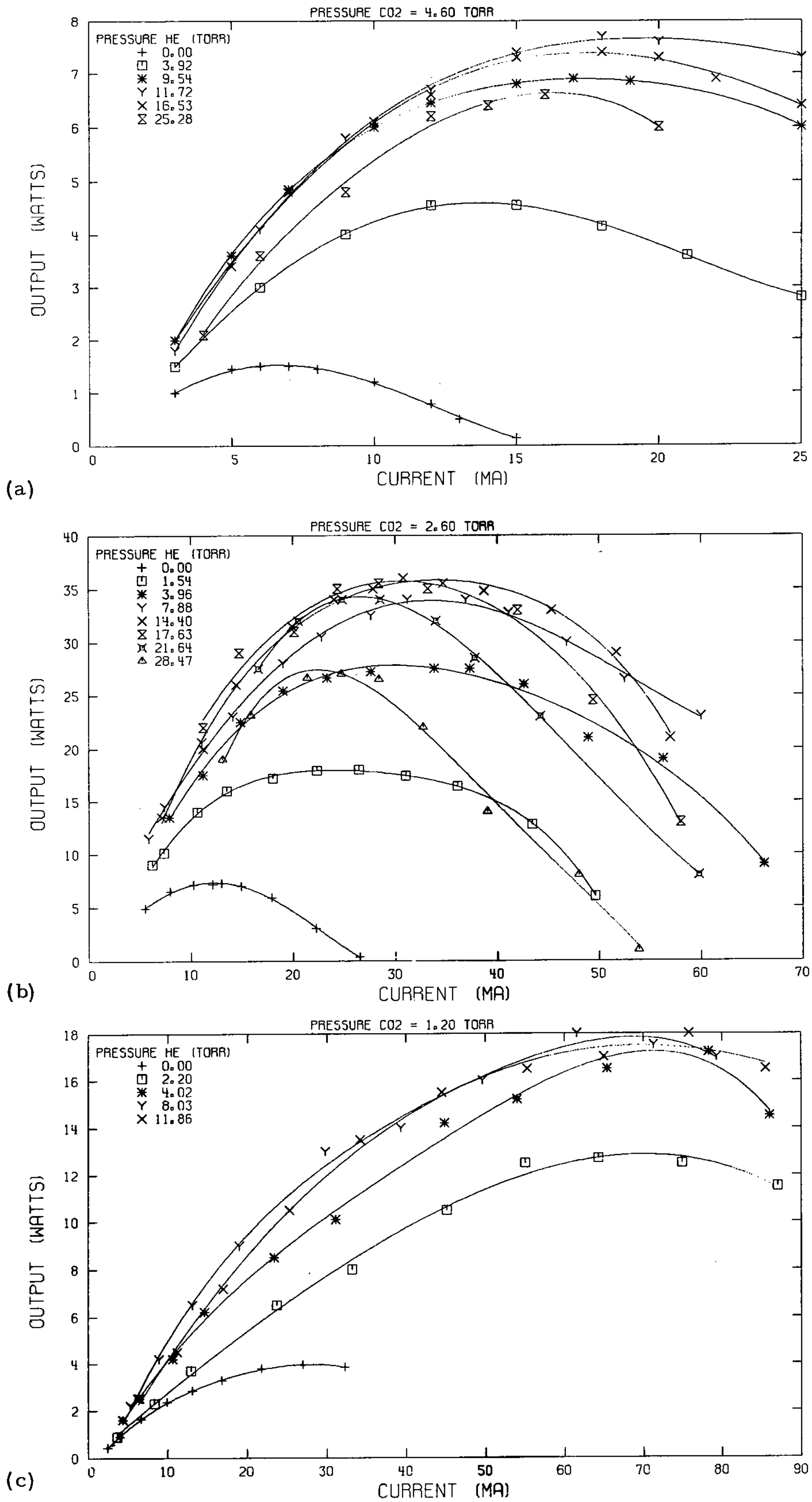


Fig. 8 - Laser output power as a function of discharge current for various partial pressures of helium (a) 10-mm bore, (b) 19-mm bore, (c) 38-mm bore

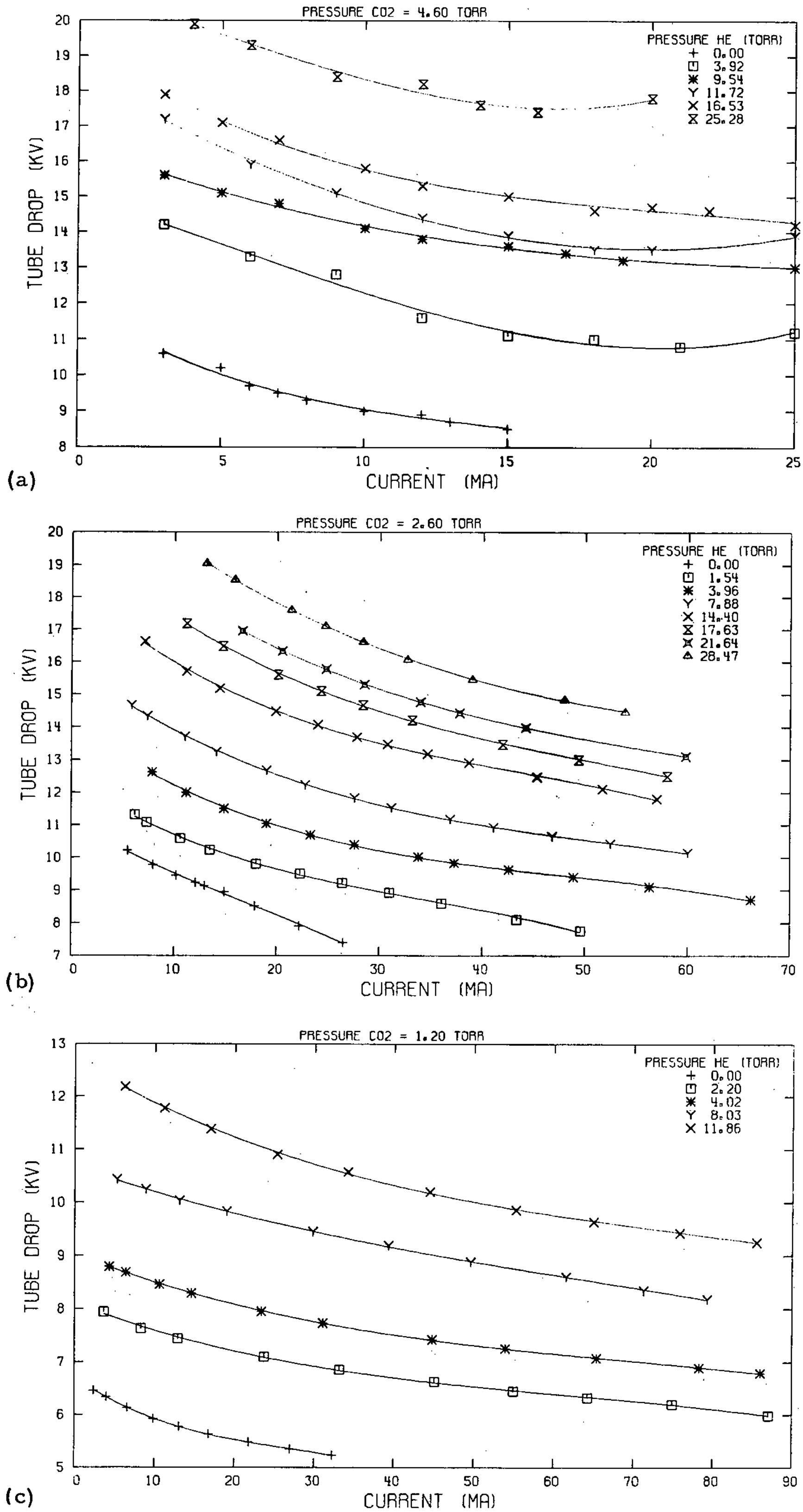


Fig. 9 - Potential drop across the discharge tube as a function of current for each helium partial pressure (a) 10-mm bore, (b) 19-mm bore, (c) 38-mm bore

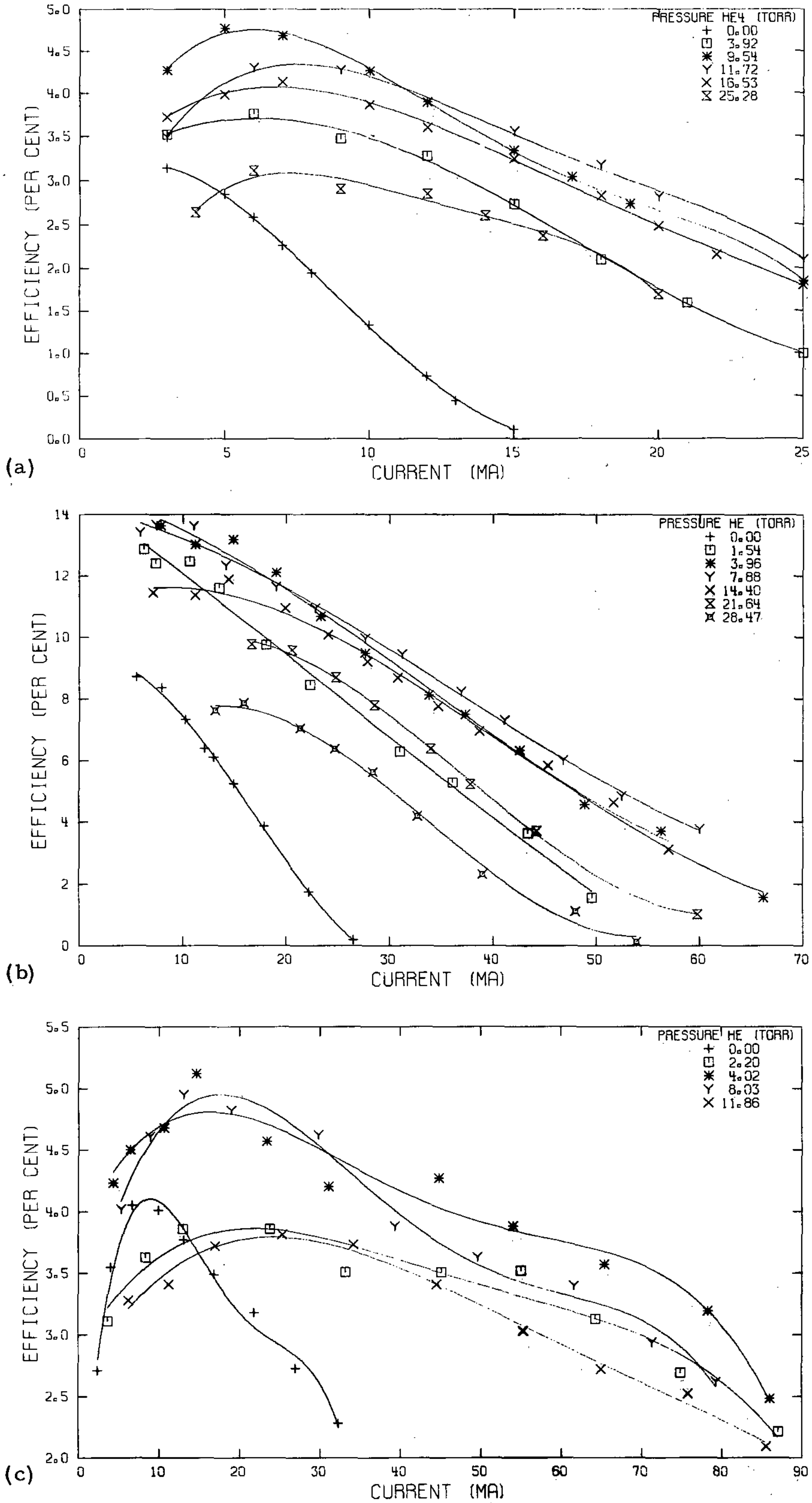


Fig. 10 - Power efficiency as a function of discharge current for each helium partial pressure (a) 10-mm bore, (b) 19-mm bore, (c) 38-mm bore

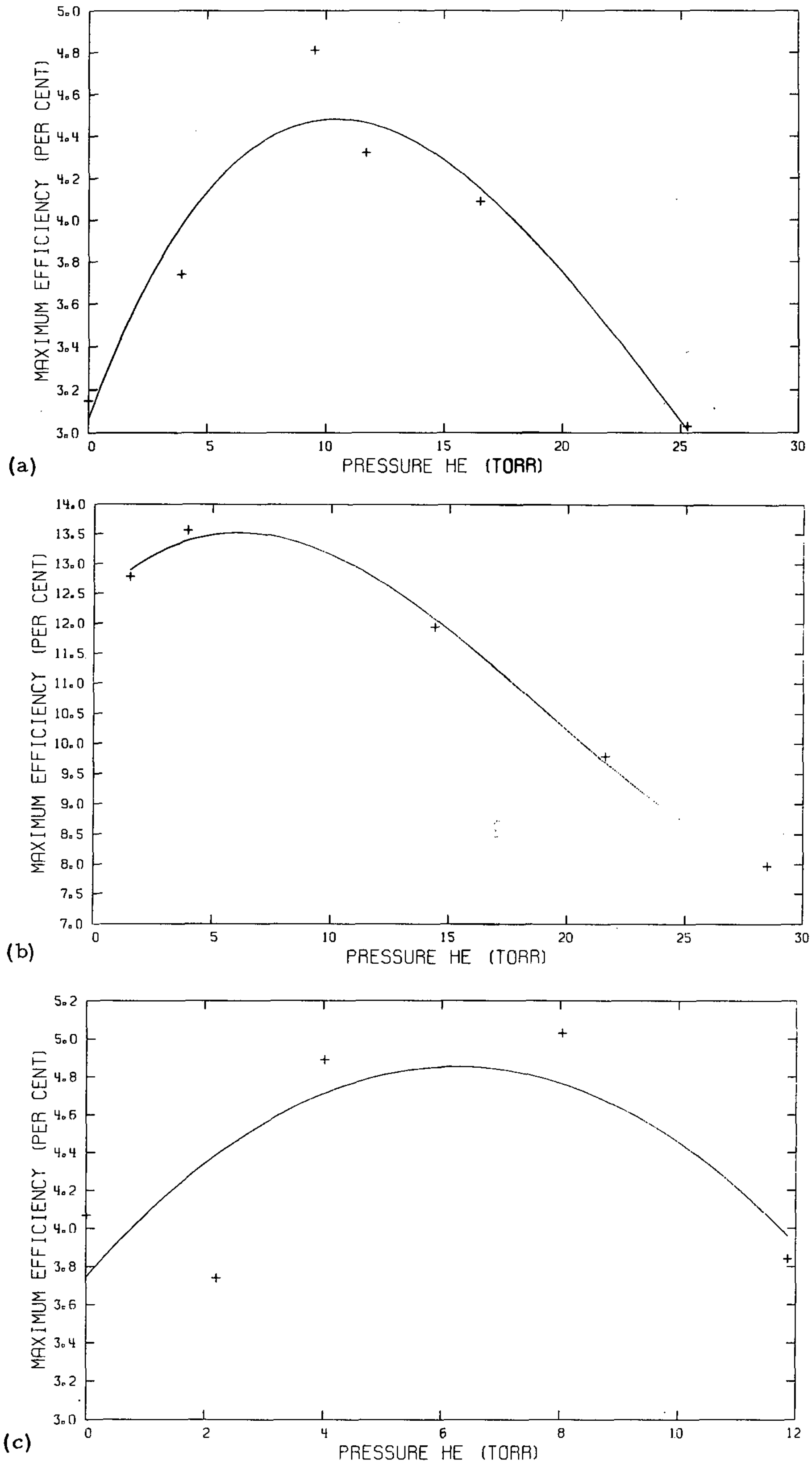


Fig. 11 - Maximum efficiency as a function of the partial pressure of helium (a) 10-mm bore, (b) 19-mm bore, (c) 38-mm bore

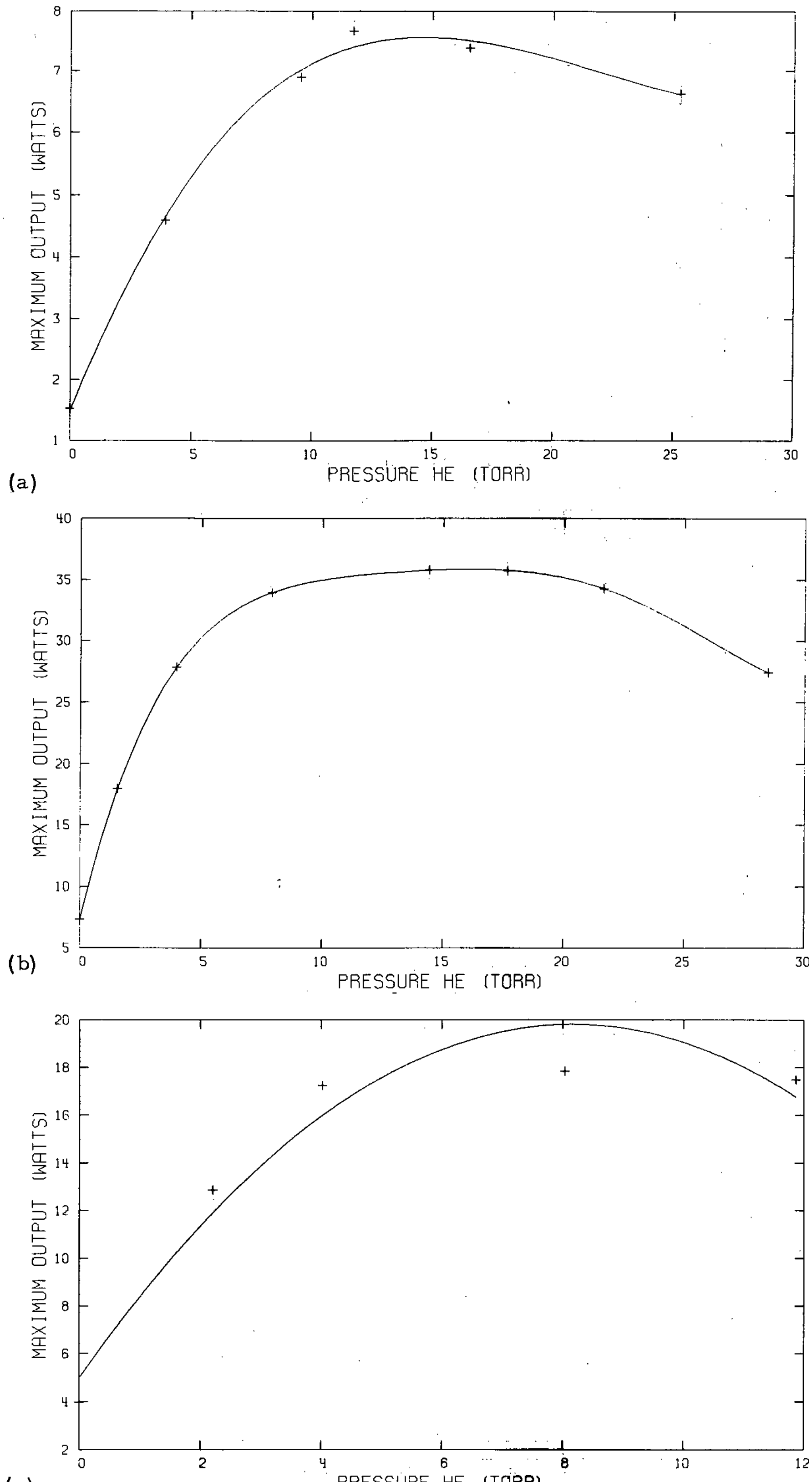


Fig. 12 - Maximum output power as a function of the partial pressure of helium (a) 10-mm bore, (b) 19-mm bore, (c) 38-mm bore

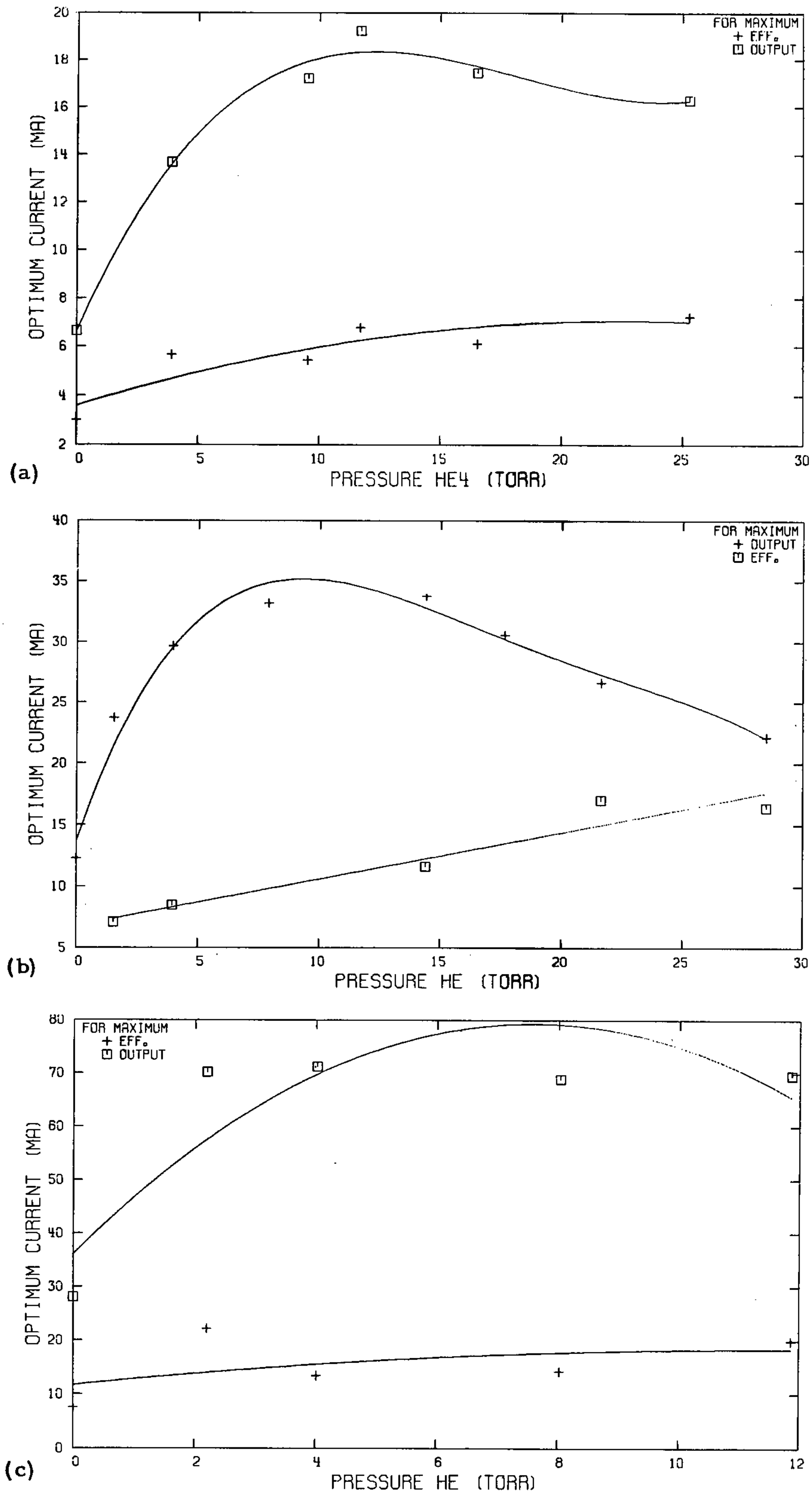


Fig. 13 - Optimum currents for maximum output power (upper curve) and for maximum efficiency (lower curve) as functions of the partial pressure of helium (a) 10-mm bore, (b) 19-mm bore, (c) 38-mm bore

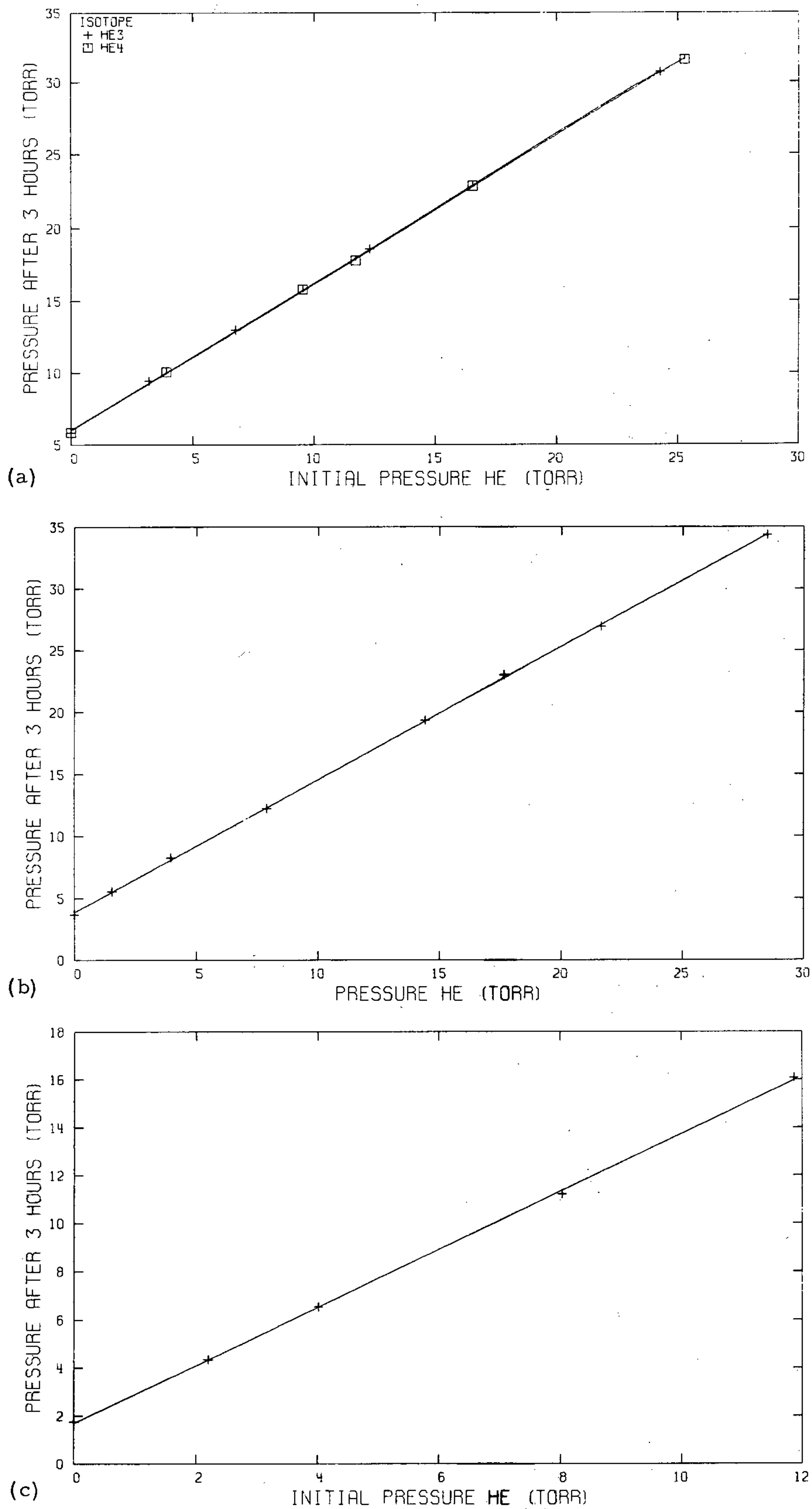


Fig. 14 - Total pressure after 3 hours of operation as a function of the partial pressure of helium (a) 10-mm bore, (b) 19-mm bore, (c) 38-mm bore

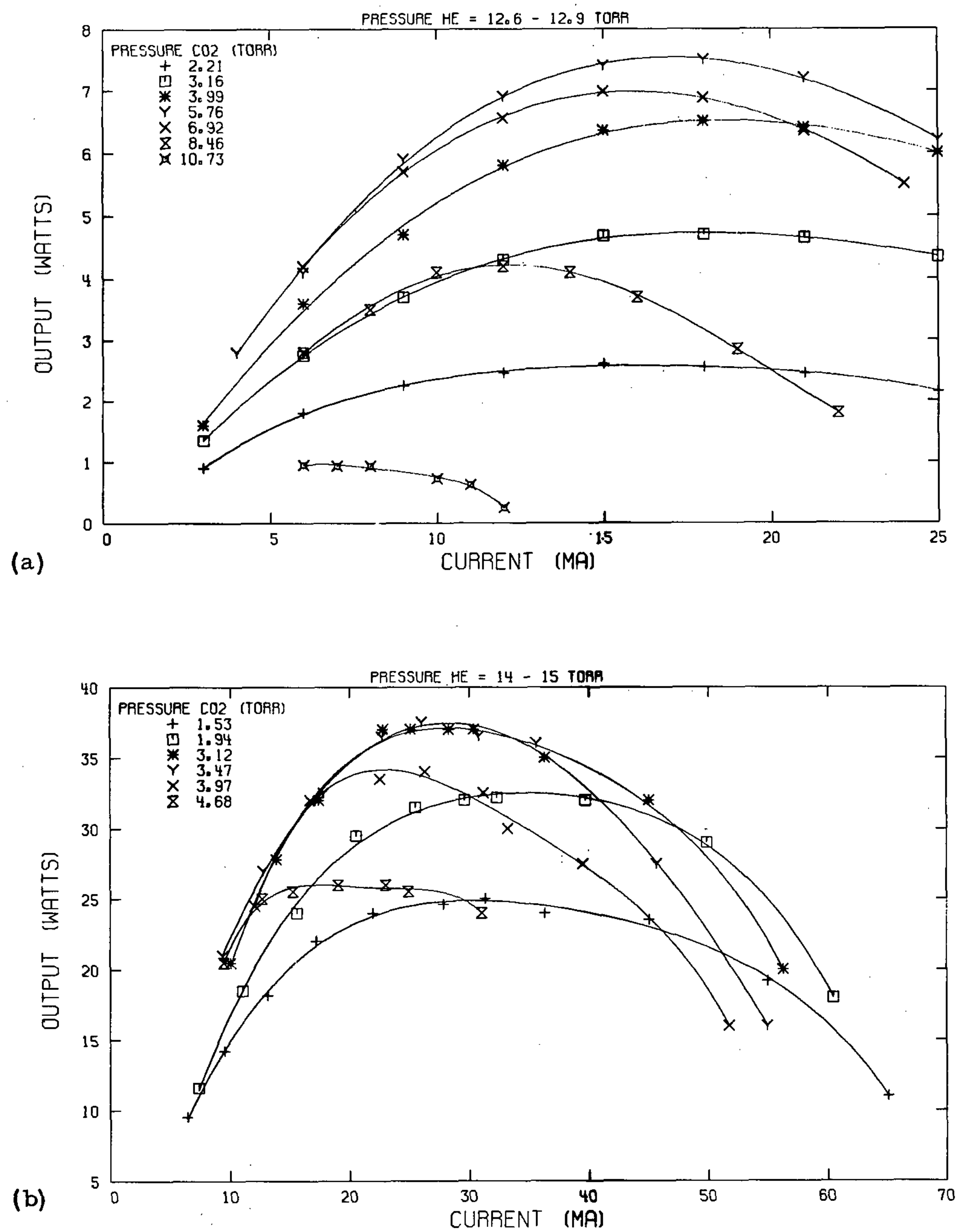
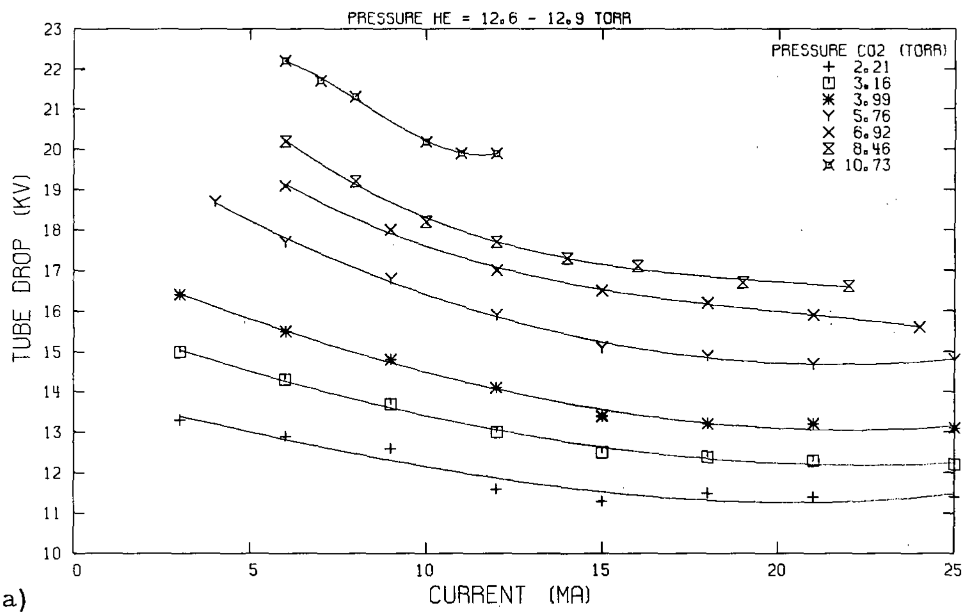
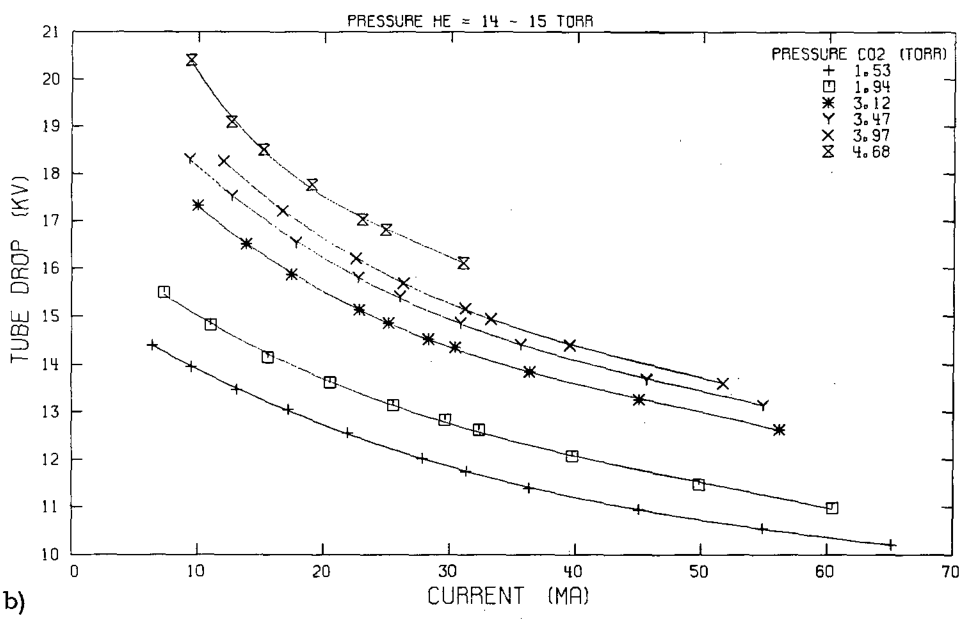


Fig. 15 - Laser output power as a function of discharge current for various CO_2 fill pressures with helium added (a) 10-mm bore, (b) 19-mm bore

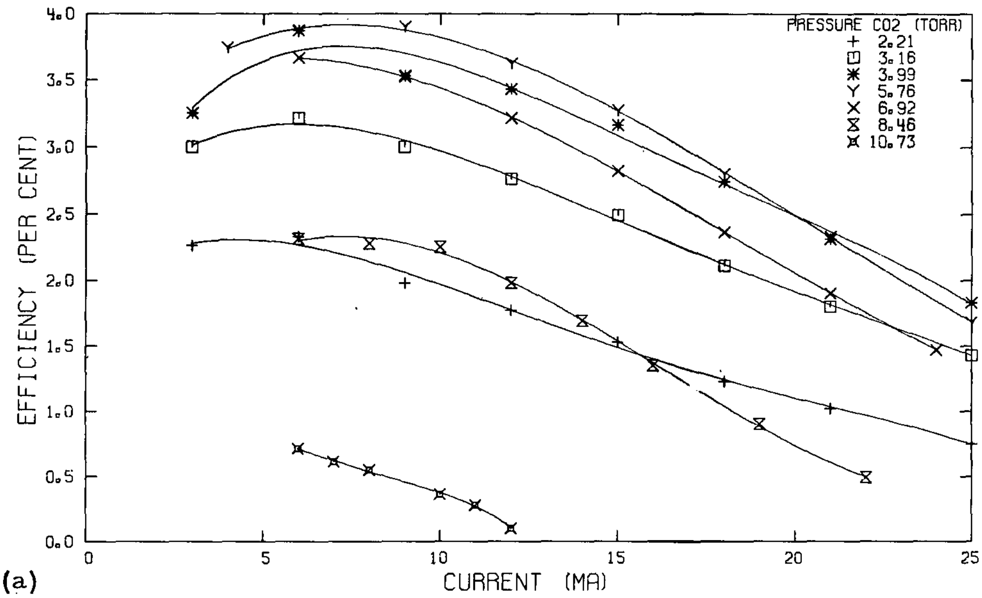


(a)



(b)

Fig. 16 - Potential drop across the discharge tube as a function of current for each CO_2 fill pressure with helium added (a) 10-mm bore, (b) 19-mm bore



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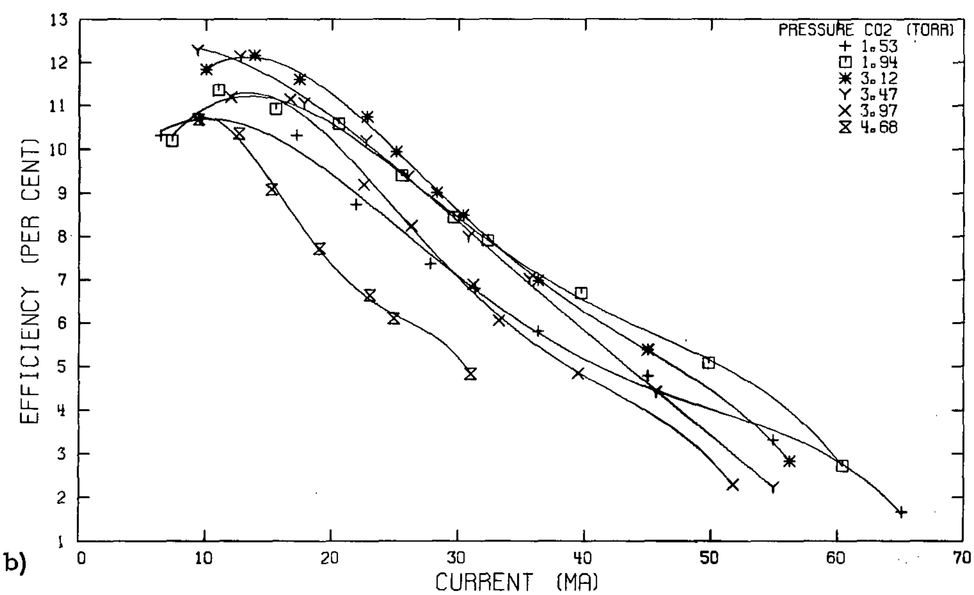
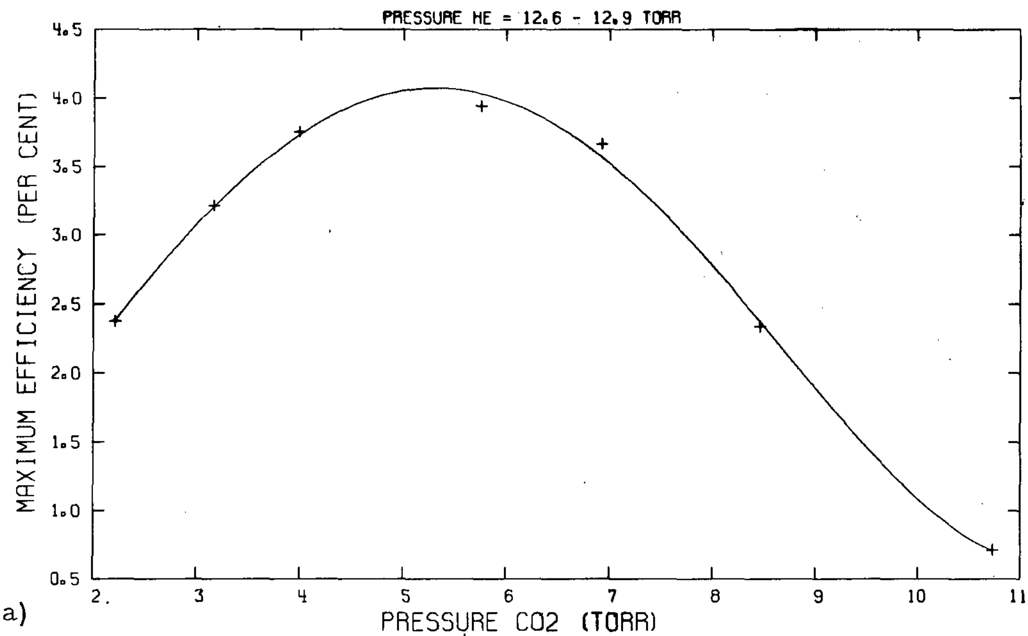


(b)

Fig. 17 - Power efficiency as a function of discharge current for each CO_2 fill pressure with helium added (a) 10-mm bore, (b) 19-mm bore



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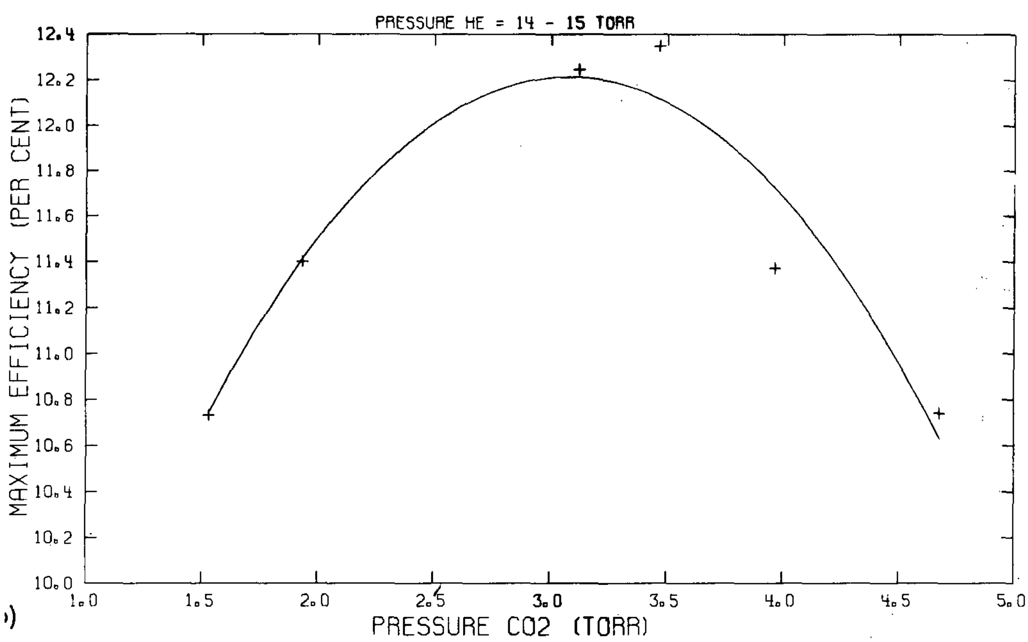

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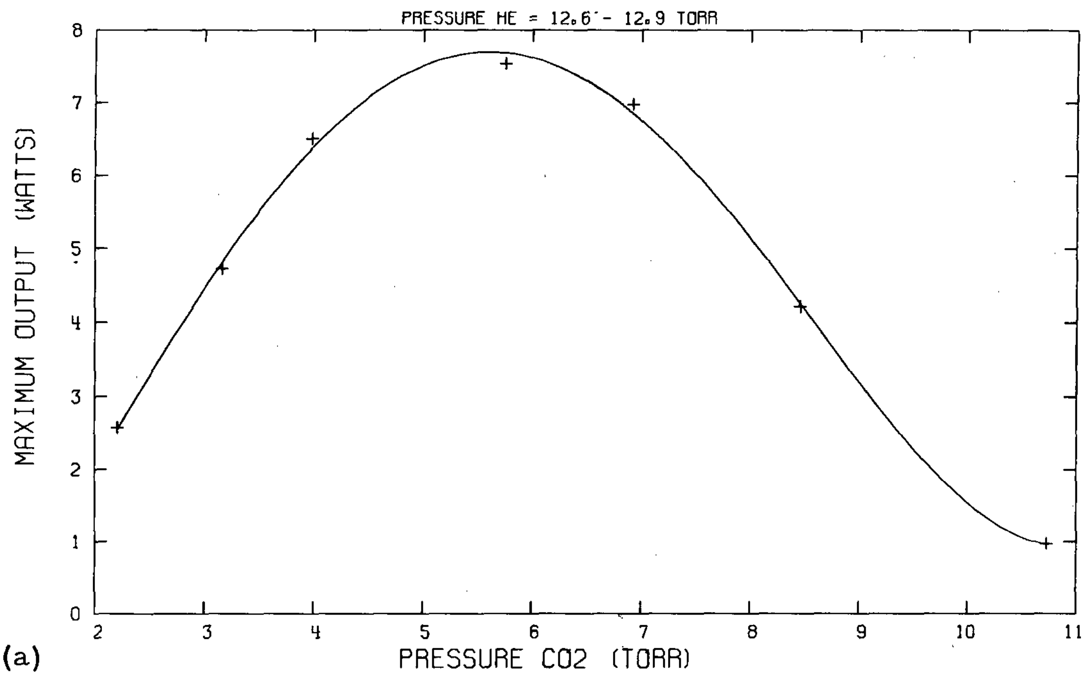
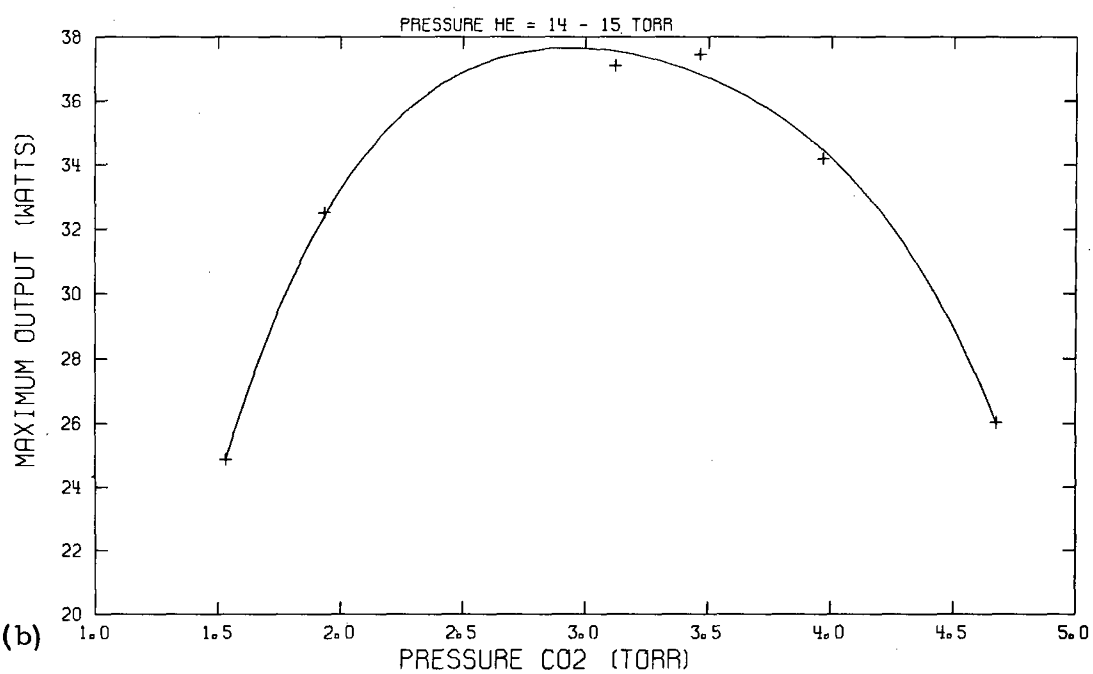
Fig. 18 - Maximum efficiency as a function of the CO_2 fill pressure with helium added (a) 10-mm bore, (b) 19-mm bore

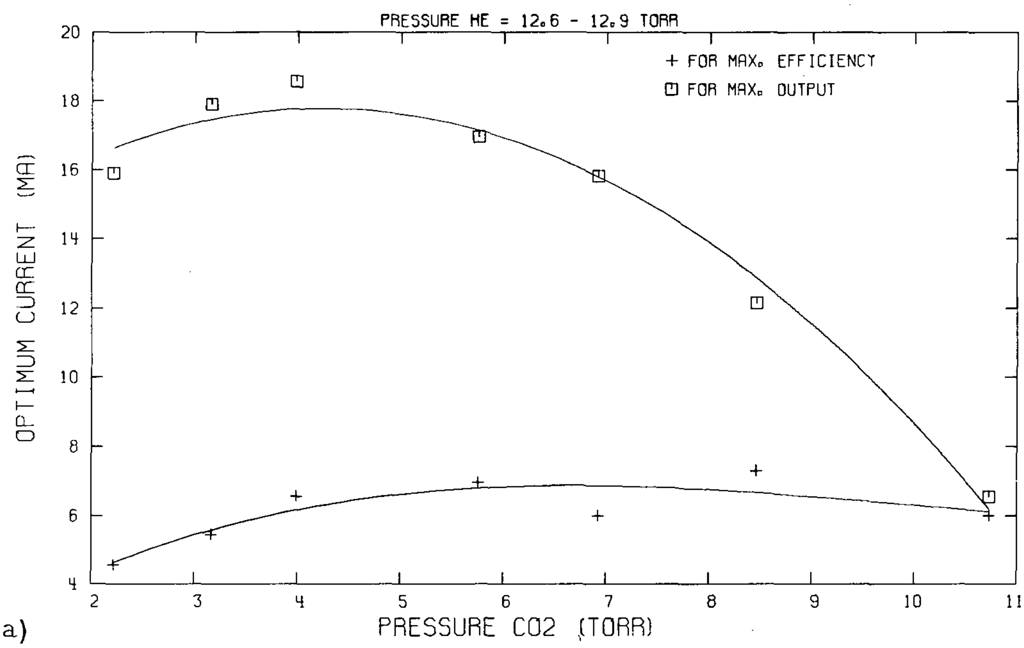


(a)

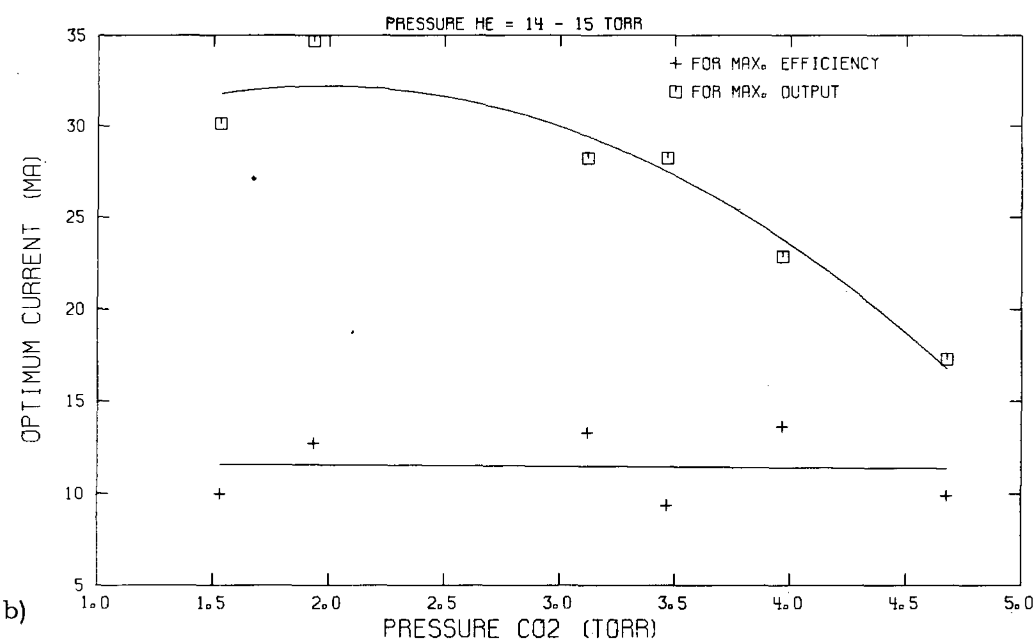


(b)

Fig. 19 - Maximum output power as a function of the CO_2 fill pressure with helium added (a) 10-mm bore, (b) 19-mm bore



(a)



(b)

Fig. 20 - Optimum current for maximum output power (upper curve) and for maximum efficiency (lower curve) as functions of the CO_2 fill pressure with helium added (a) 10-mm bore, (b) 19-mm bore

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13. ABSTRACT

This report presents experimental data on the output power and efficiency of the sealed-off CO_2 laser as a function of discharge current, the initial fill pressures of CO_2 and He, and the tube diameter. The optimum fill pressure of pure CO_2 for maximum power output and efficiency was found to be approximately 5/d Torr, where d is the tube diameter expressed in cm. At this pressure the optimum current for maximum power output was about 7d mA. The output power can be increased by a factor of five with the addition of about 10 Torr of He. With He, the optimum current for maximum power output was approximately 18d mA.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Carbon dioxide						
Output power						
Pressure						
Discharge current						
Lasers, carbon dioxide						